

# $Z(ee) + \geq n$ Jets Cross Section

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- Overview (Samples, selection criteria, ...)
- Corrections (EM, Trigger, Tracking, ...)
- Data vs MC comparisons
- Cross section unsmeearing
- $Z(ee) + \geq n$  Jets cross sections
- Systematics
- Summary



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# Samples

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- **Data:**
  - Lumi = 343 pb<sup>-1</sup>
  - Run range: 20 April 2002 - 28 June 2004 (Runs 151,817 - 194,566)
  - Pass 2 (T42 enabled)
  - JES 5.3
  - EM1TRK skim
  - Single EM triggers
  - Rejecting bad runs (CAL, SMT, CFT, Jet/Met, Lumi)
  - Processed with ATHENA (p16-br-03)
- **MC:**
  - $Z/\text{Gamma}^*$   $\rightarrow e^+e^- + X$  400k Pythia
  - $Zj \rightarrow ee j$ : 150k Alpgen + Pythia
  - $Zjj \rightarrow ee jj$ : 180k Alpgen + Pythia
  - $Zjjj \rightarrow ee jjjj$ : 15k Alpgen + Pythia
  - Processed with ATHENA (p16-br-03)

# Selection Criteria

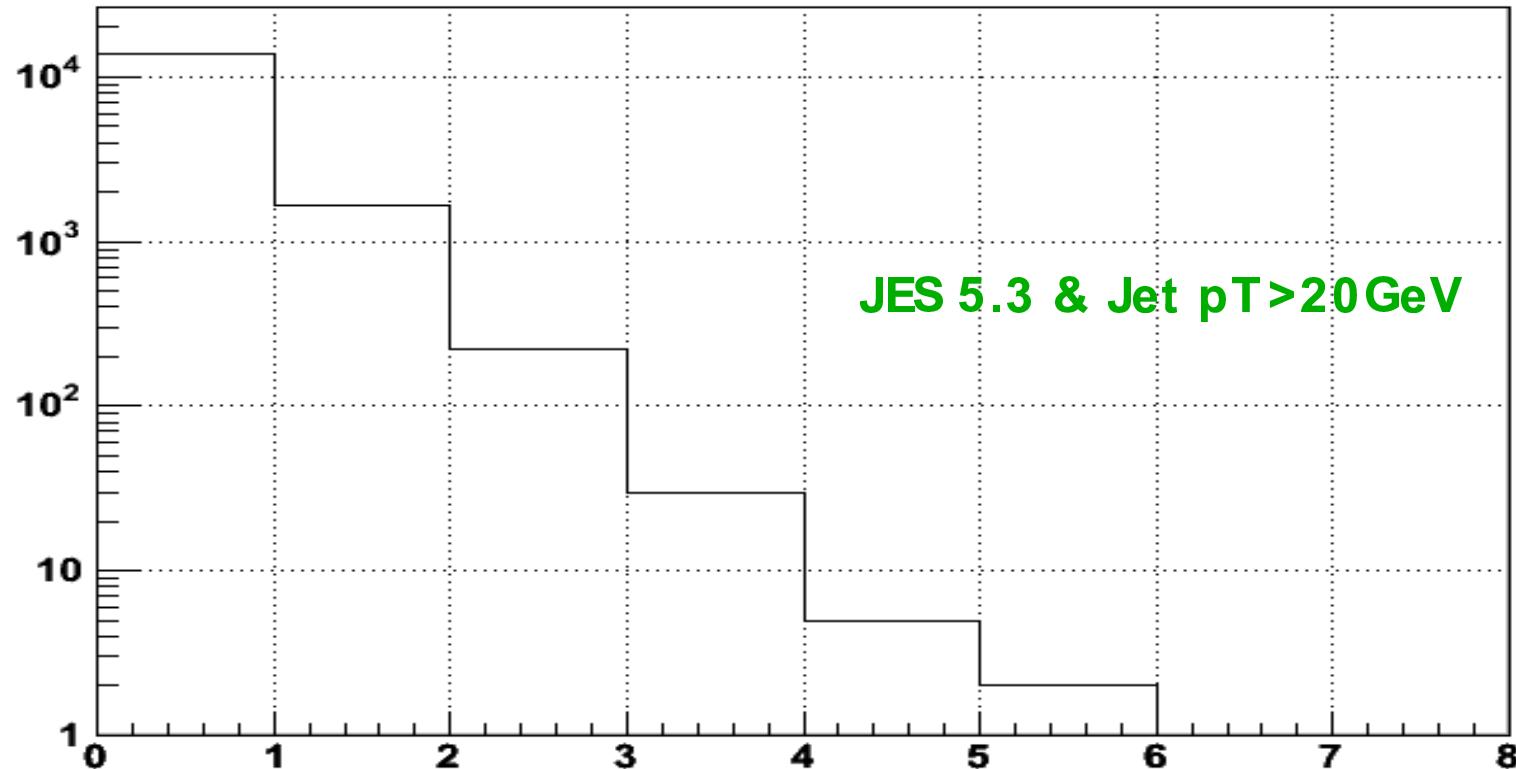
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- Removing bad runs/LBNs & duplicate events
- PVX cut:  $|z| < 60\text{cm}$
- Using unprescaled single EM triggers
- Electron selection:
  - $|ID| = 10, 11$
  - $\text{EMF} > 0.9$
  - $\text{Iso} < 0.15$
  - $\text{HMx}(7) < 12$
  - $p_T > 25\text{GeV}$
  - $|\text{det\_eta}| < 1.1$
  - Including phi cracks
- Z selection:
  - $75\text{GeV} < M_{ee} < 105\text{GeV}$
  - At least one track-matched electron
  - At least one electron needs to fire the trigger
- Jet selection:
  - $0.05 < \text{EMF} < 0.95$
  - $\text{HotF} < 10$
  - $N90 > 1$
  - $\text{CHF} < 0.4$
  - L1conf
  - JES corrected  $p_T > 20\text{GeV}$
  - $|\text{phys\_eta}| < 2.5$
  - Removal of jets overlapping with electrons from Z within  $dR$  of 0.4

# Jet Multiplicities

Inclusive Jet Multiplicities

(Data)



Inclusive # of jets

# events (uncorr)

0

1

2

3

4

5

13,893

1,646

219

30

5

2



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4

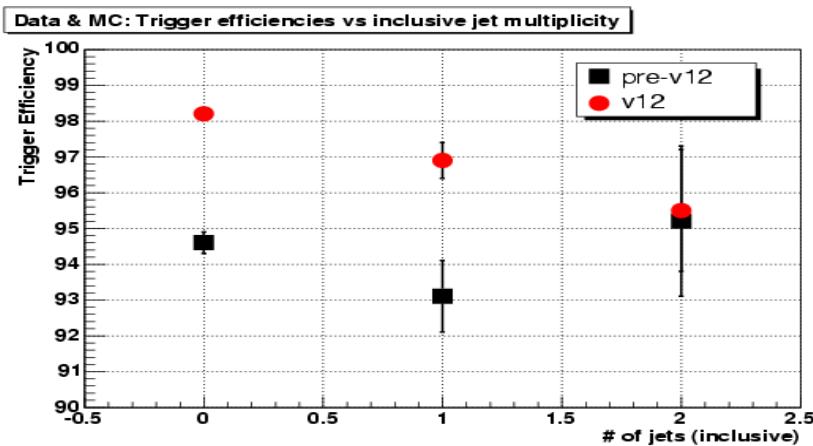
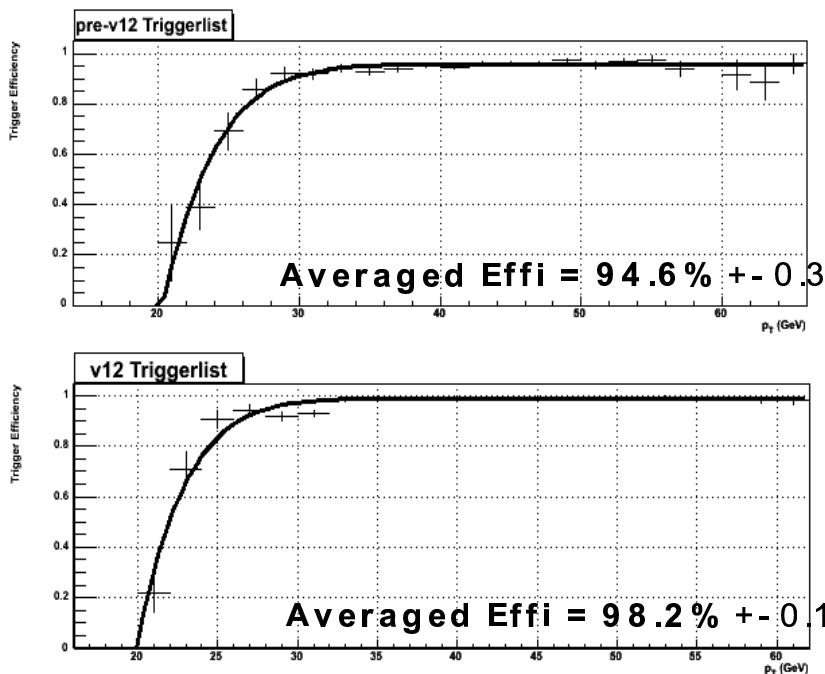
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# Corrections

- Trigger
- EM Reco and ID
- EM-Track Match
- Jet Reco and ID
- Acceptance

# Trigger Correction

- Method: tag-and-probe method, where the probe electron is tested for matching trigger objects at L1, L2 and L3
- Need to separate trigger efficiencies for pre-v12 and v12 data
- No big variations in overall trigger efficiencies vs jet multiplicity are observed
- Applying trigger efficiency vs  $p_T$  as corrections (weights) to all jet multiplicity samples

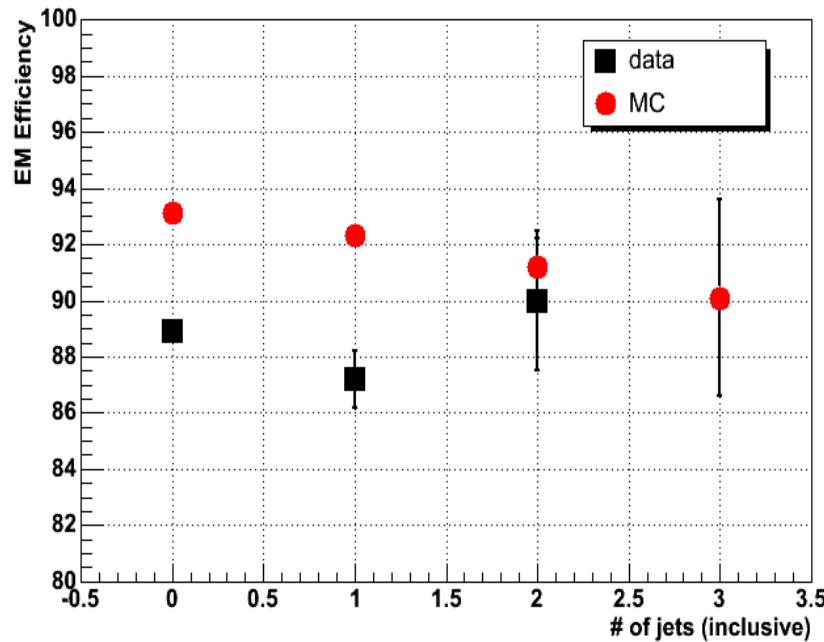


Jetmult	pre-v12	v12
0	94.6%+/-5.0%	98.2%+/-5.0%
1	93.1%+/-5.0%	96.9%+/-5.0%
2	95.2%+/-5.0%	95.5%+/-5.0%

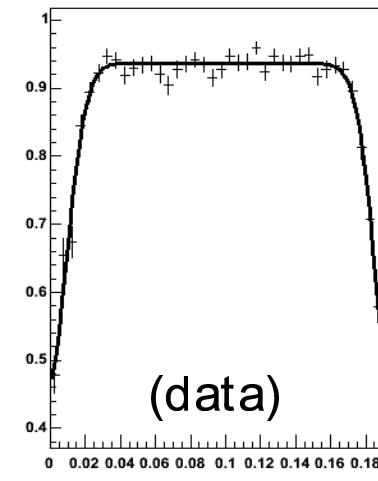
# EM Reco/ID Correction

- Using a tag-and-probe method:  
tag = tight electron, probe = track
- We derive parameterized (vs pT  
and Phi) efficiencies for Z(ee)+X  
sample

Data & MC: EM efficiencies vs inclusive jet multiplicity

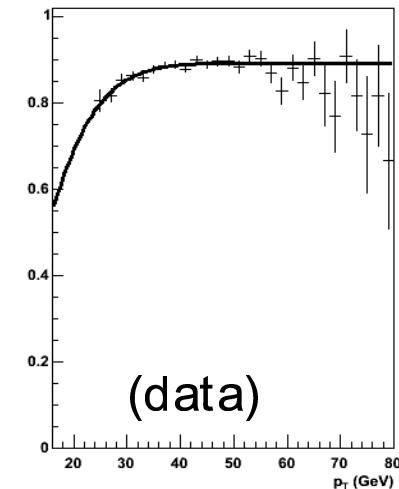


eff\_EM\_phi\_0jet



(data)

eff\_EM\_pt\_0jet



(data)

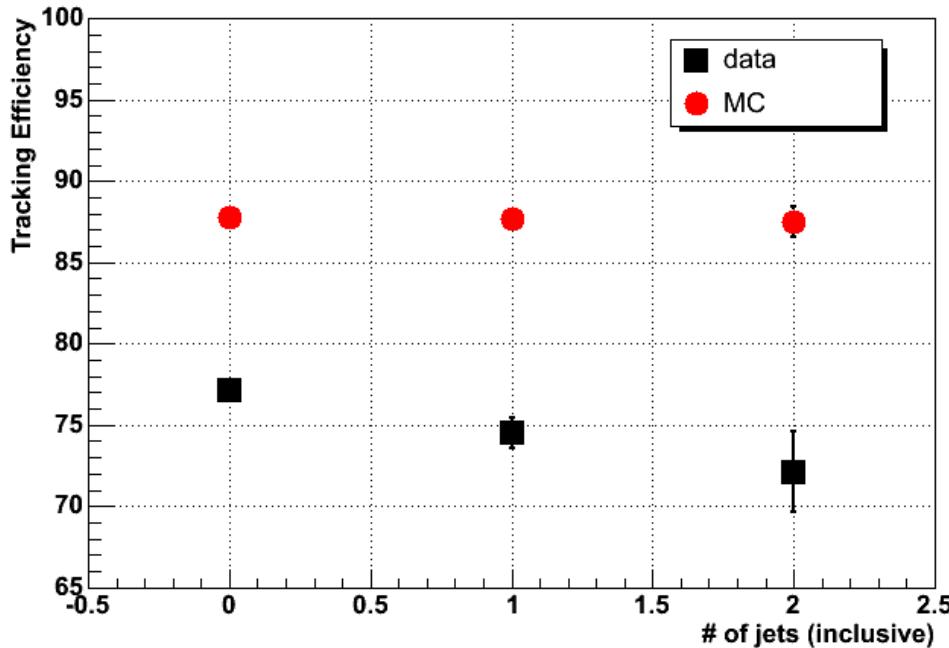
- We apply the parameterized efficiency curves as corrections (weights) to all jet multiplicity samples in data

Jetmult	data (w/ syst)
0	88.9% $\pm$ 3.0 %
1	87.2% $\pm$ 3.0 %
2	90.0% $\pm$ 3.0 %

# EM-Track Match Correction

- Method:
  - # of signal events in  $M_{ee}$  histogram when requiring 1 track match
  - # of signal events in  $M_{ee}$  histogram when requiring 2 track matches
  - Take the ratio to get an averaged efficiency

Data & MC: Tracking efficiencies vs inclusive jet multiplicity



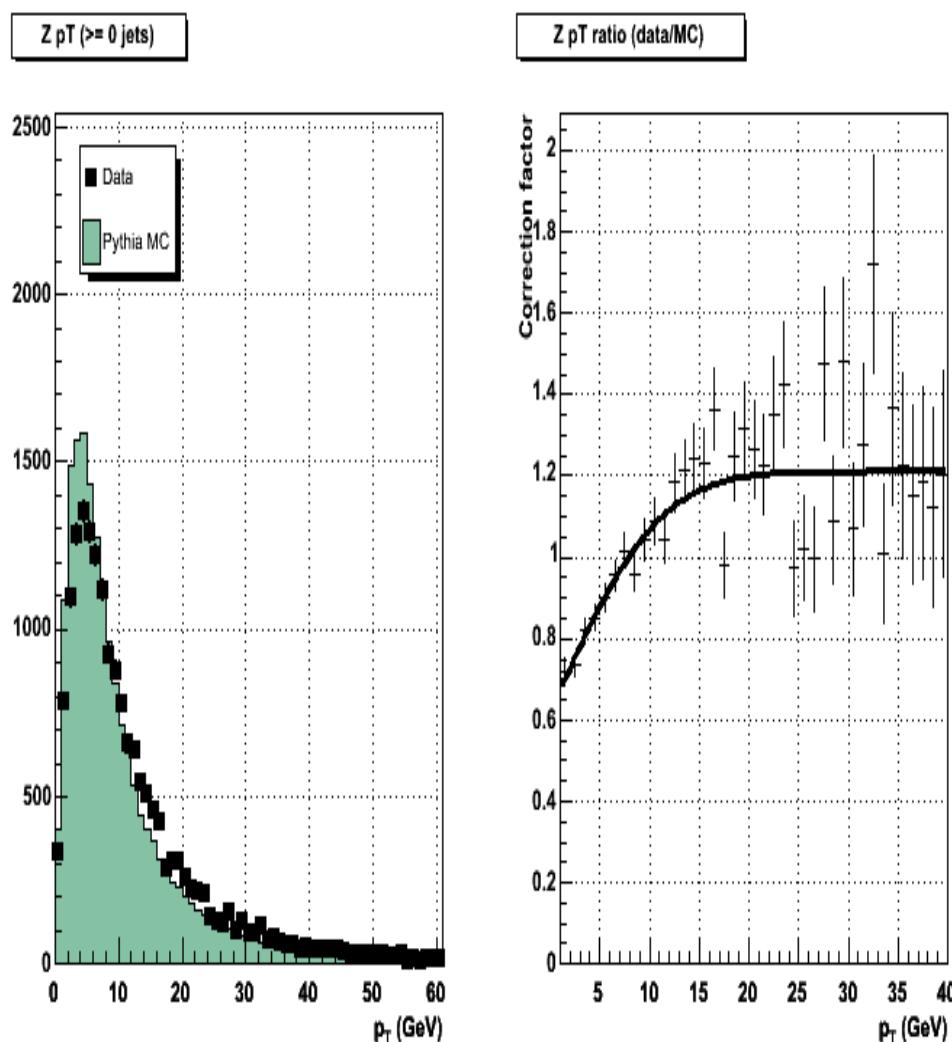
- MC: Applying the averaged efficiency from 0-jet sample as corrections (weights) to all other jet multiplicity samples
- Data: Applying 0-jet, 1-jet, 2-jet values to the respective jet multiplicity samples and using 2-jet values for 3, 4, 5 jet samples



Jetmult	Data (w/ syst)
0	77.1% $\pm$ 0.3%
1	74.5% $\pm$ 0.9%
2	72.1% $\pm$ 2.5%
3	72.1% $\pm$ 3.5%
4	72.1% $\pm$ 5.6%
5	72.1% $\pm$ 7.9%

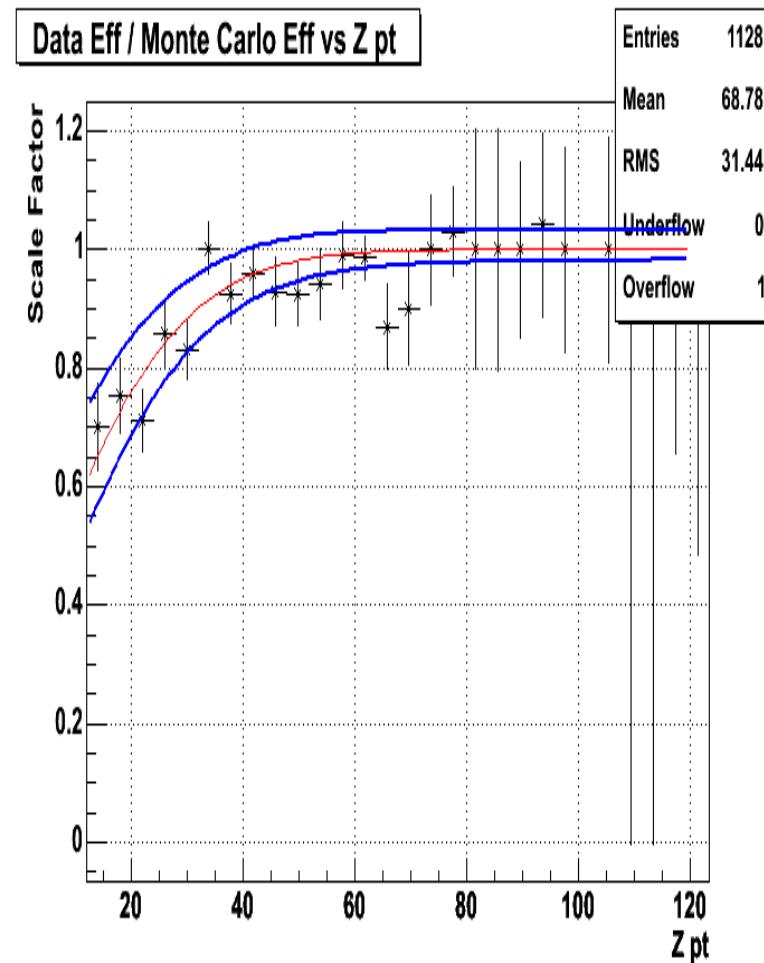
# Z pT Correction

- Needed to adjust Pythia MC to data
- After applying all the previous corrections we compare the Z pT between data and MC
- We take the ratio of data over MC and apply it as an additional correction to the Pythia MC
- Not needed for Alpgen samples



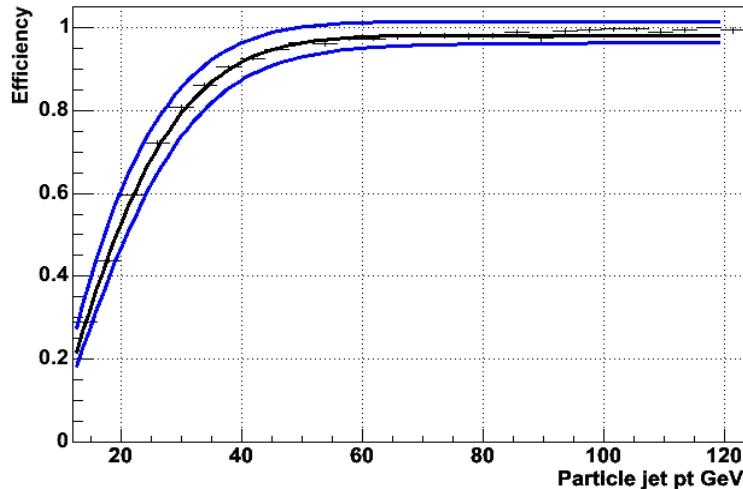
# Jet Reco/ID Correction (1)

- Based on work done by **James Heinmiller**
- Deriving scaling factor using the Z pT method:
  - Looking for a jet recoiling against a Z boson (opposite in Phi)
  - Using Z pT method in both data and MC and taking ratio yields a scaling factor
- Estimating jet reco/ID efficiency in MC:
  - Matching particle level jets with CAL jets ( $\Delta R=0.4$ )
  - Parameterized vs smeared particle jet pT (data resolution smearing)
- We adjust the MC jet reco/ID efficiency with the scaling factor to match the data

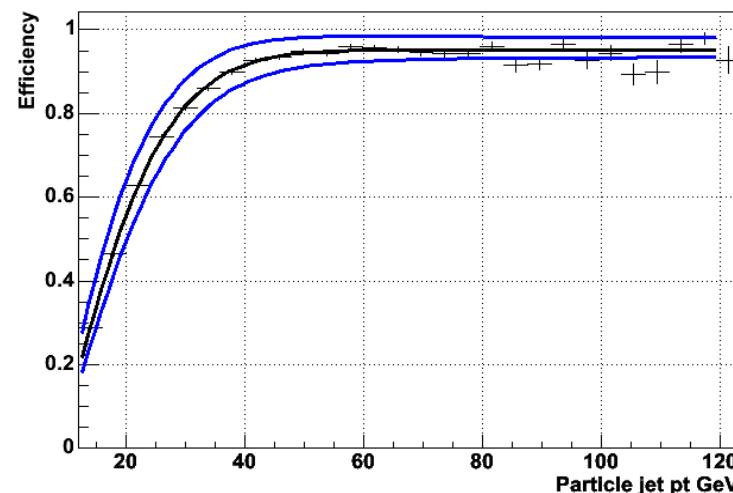


# Jet Reco/ID Correction (2)

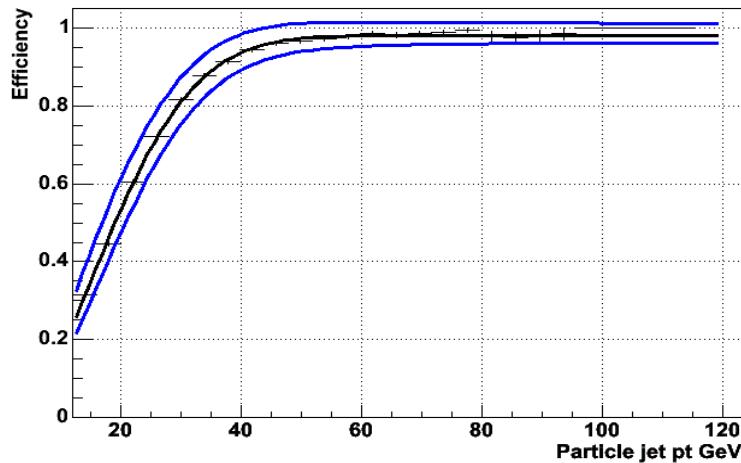
Straight Eff with Scale Factor - Central



Straight Eff with Scale Factor - ICR



Straight Eff with Scale Factor - Forward



- Jet reco/ID efficiencies in data with errors (statistical, MET cut)
- Detailed note is in preparation



# Acceptance Correction

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- Kinematic and geometric efficiency for Z's
  - $|PVZ| < 60\text{cm}$
  - 2 electrons with  $pT > 25\text{GeV}$ ,  $|\text{det\_eta}| < 1.1$
  - $75\text{GeV} < M_{ee} < 105\text{GeV}$
- Vs jet multiplicity based on the number of p.l jets with  $pT > 20\text{GeV}$ ,  $\text{det\_eta} < 2.5$

$$\text{Acc} = \frac{\text{\# of CAL Z's with } n \text{ p.l. jets } (pT > 20, |\text{eta}| < 2.5)}{\text{\# of p.l. Z's with } n \text{ p.l. jets } (pT > 20, |\text{eta}| < 2.5)}$$

Jetmult	Acceptance
0	$21.4\% \pm 0.1\%$
1	$25.1\% \pm 0.2\%$
2	$25.4\% \pm 0.2\%$
3	$27.4\% \pm 0.3\%$
4	$28.5\% \pm 0.7\%$
5	$30.3\% \pm 1.9\%$



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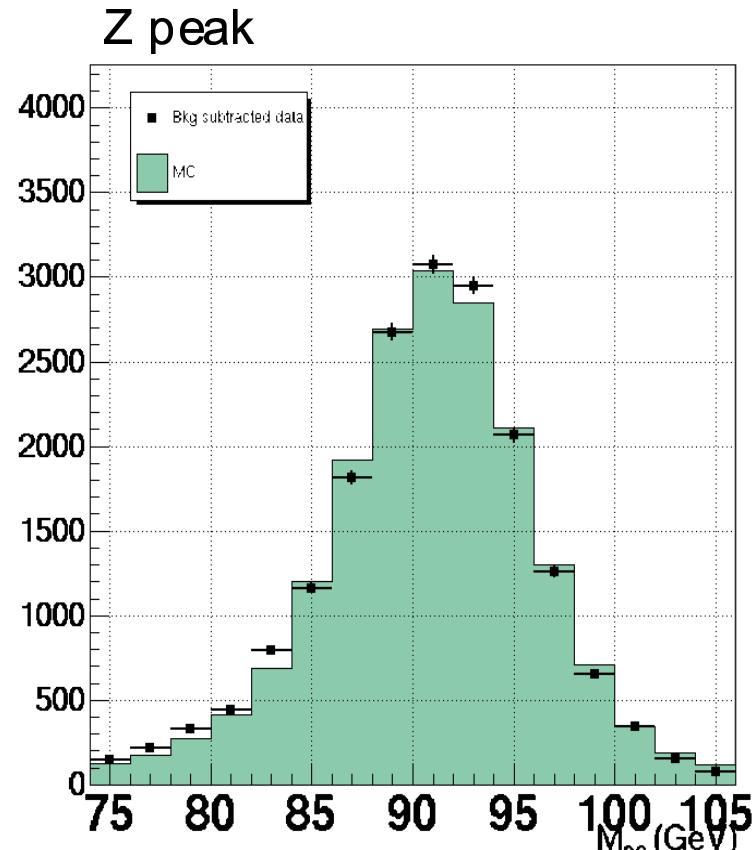
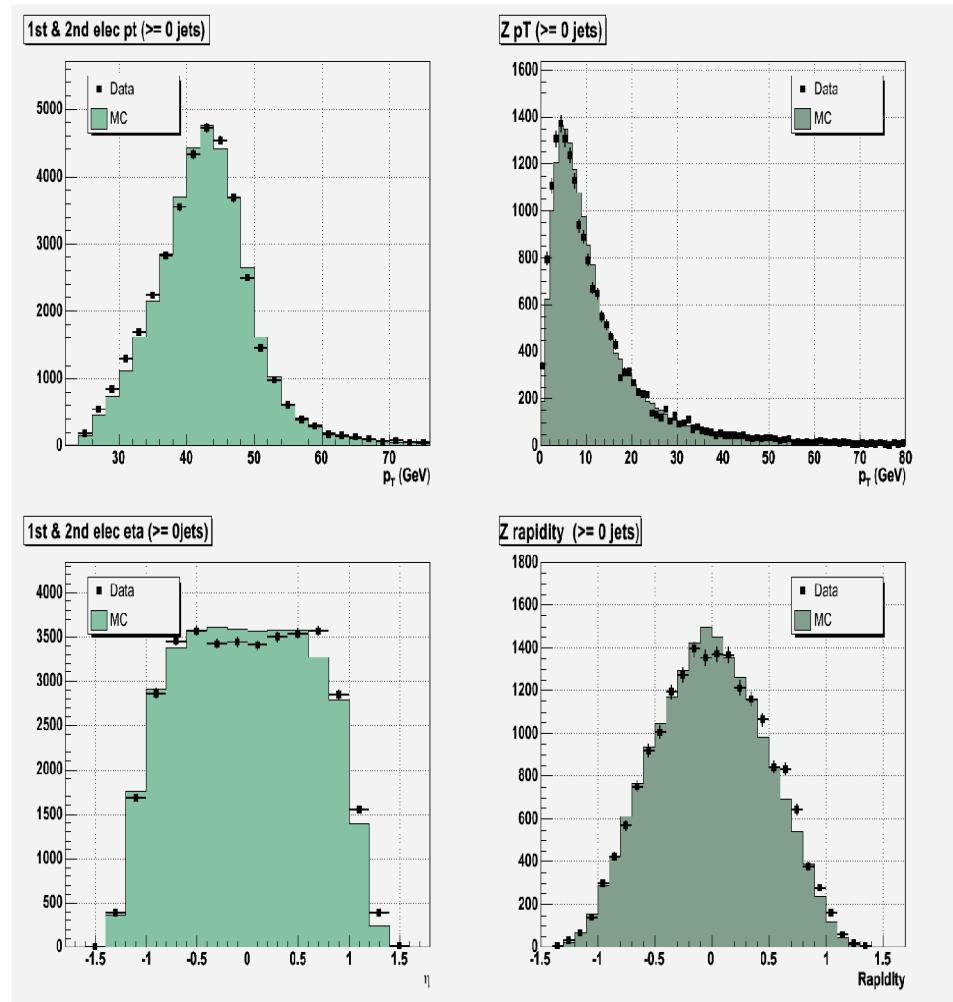
# Data vs MC

- Applying corrections: EM, Trigger, Tracking, Z pT, Jet Reco scaling
- Normalized wrt area

# $Z(ee) + X$ : Electrons and Zs

Sample size  $\approx 14k$  events

MC = Pythia



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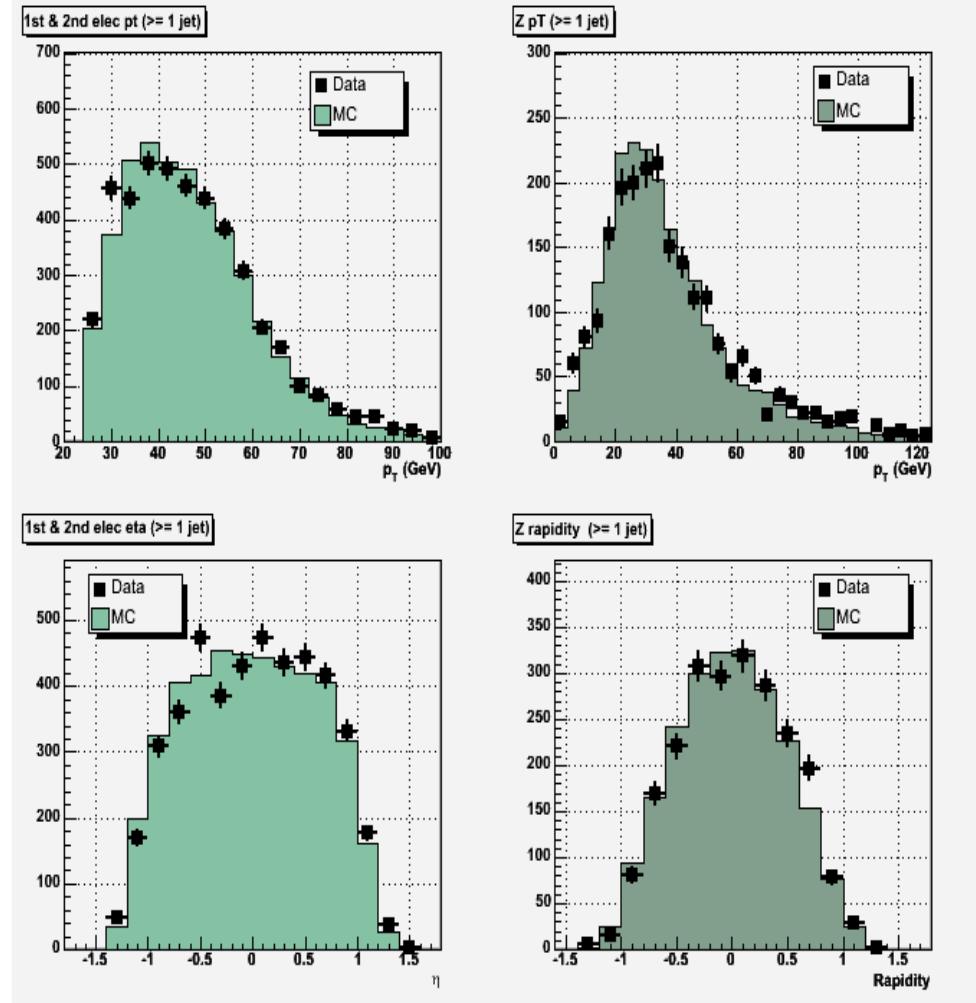
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14

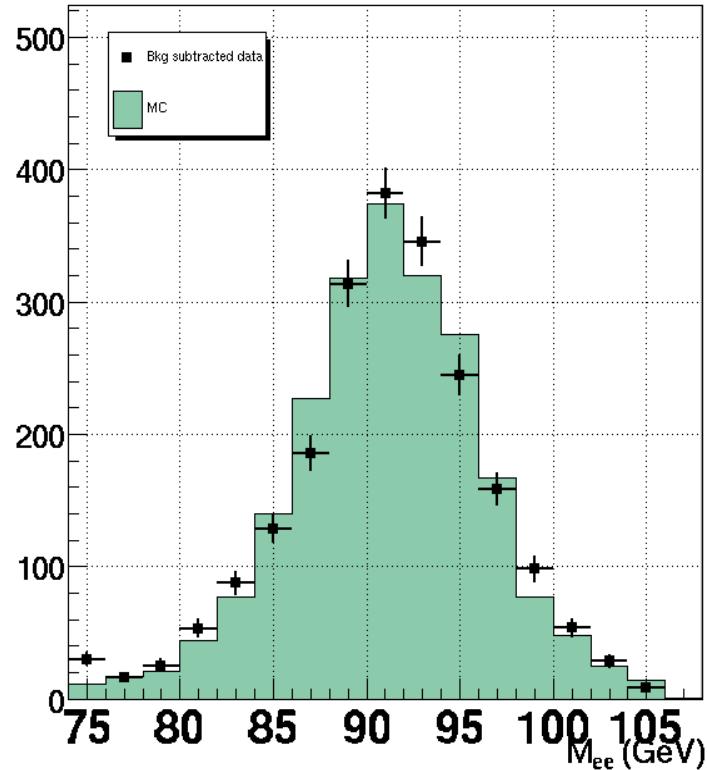
# $Z(ee) + \geq 1\text{jet(s)}$ : Electrons and Zs

Sample size  $\approx 1.6k$  events

MC = Zj Alpgen



Z peak



Mass = 91.40 GeV

Width = 4.09 GeV



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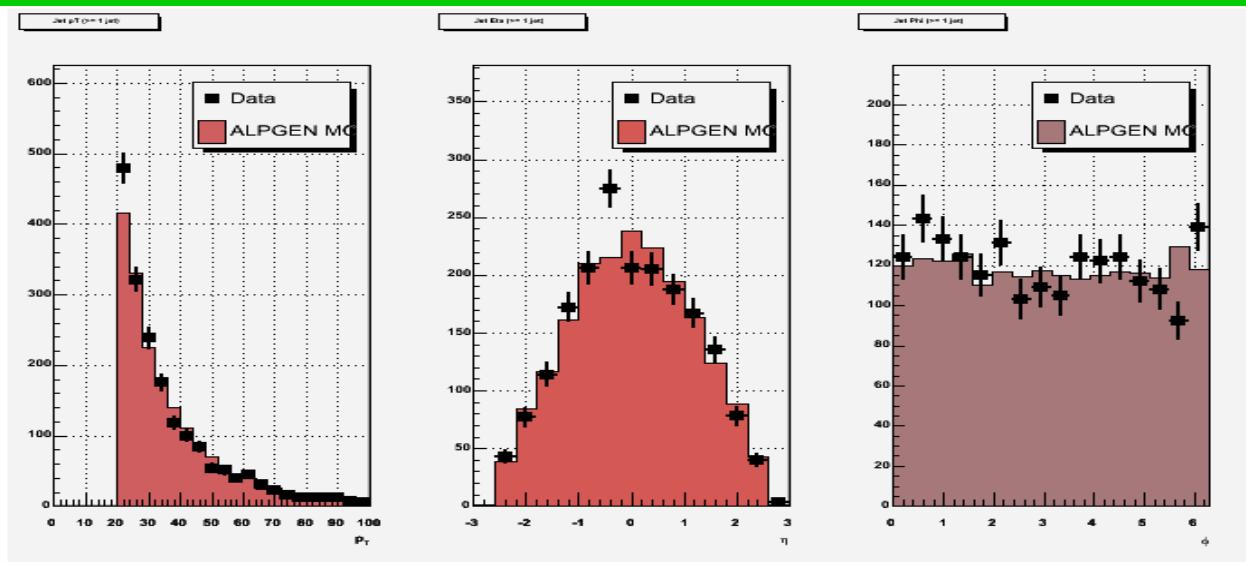
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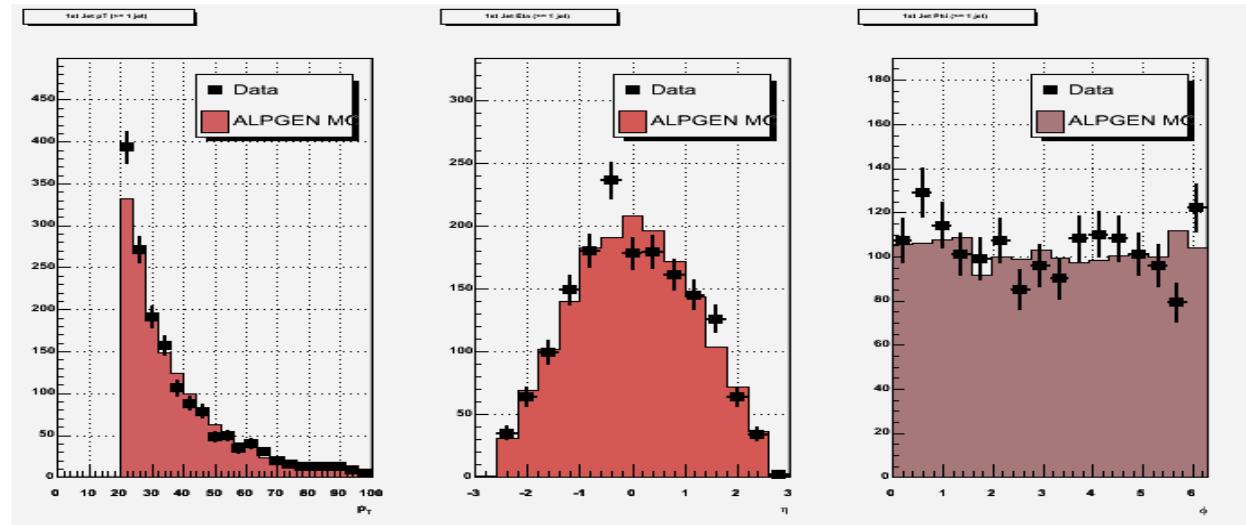
15

# $Z(ee) + \geq 1\text{jet(s)}$ : Jets

All Jets



Lead  
jet



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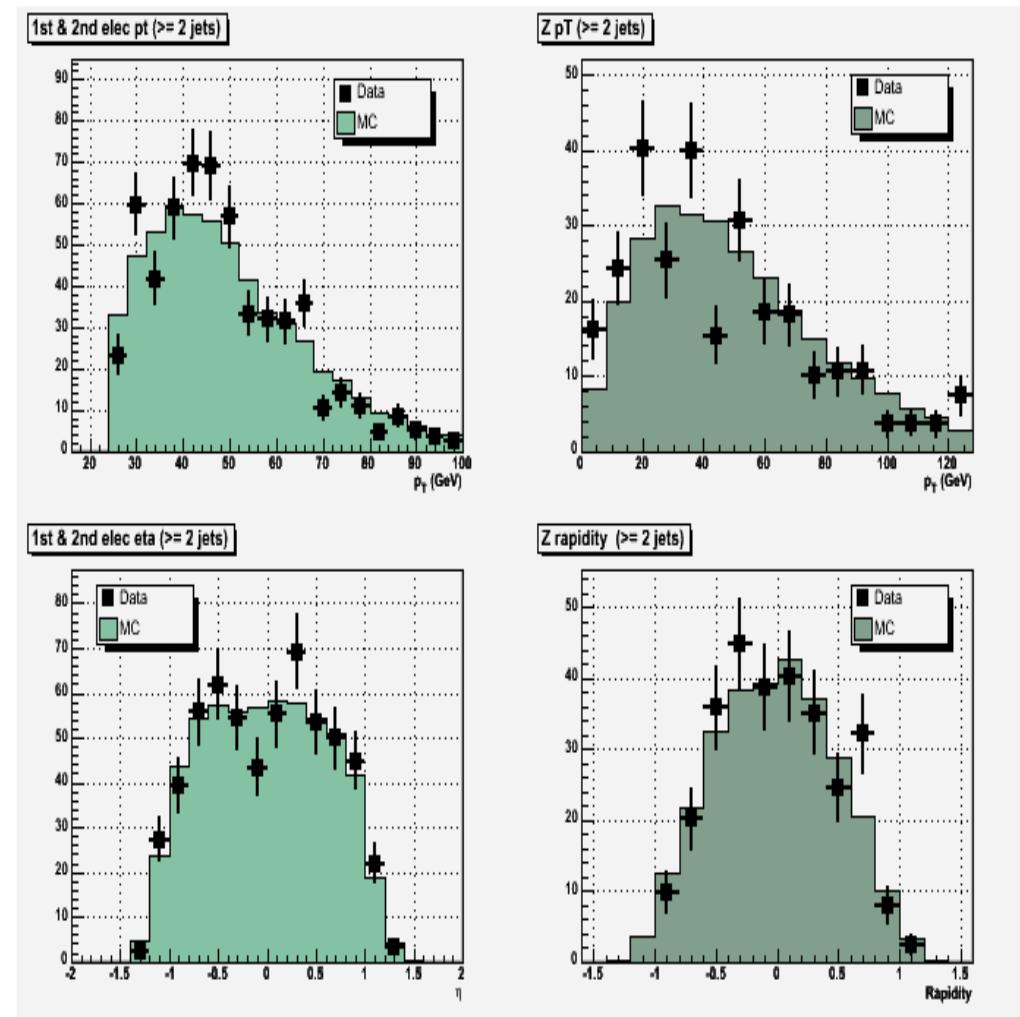
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16

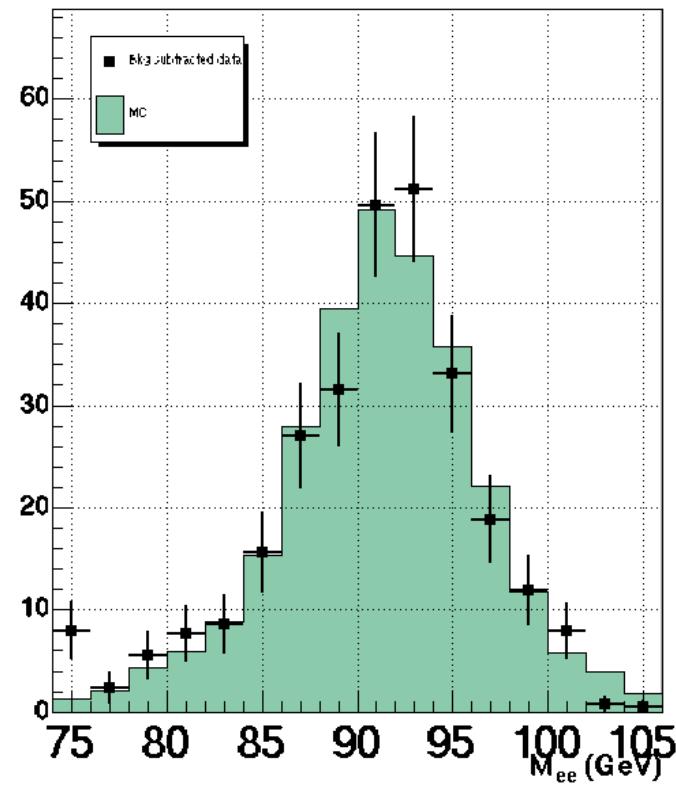
# $Z(ee) + \geq 2\text{jet(s)}$ : Electrons and Zs

Sample size  $\approx 200$  events

MC =  $Zjj$  Alpgen



Z peak



Mass = 91.47 GeV

Width = 3.72 GeV



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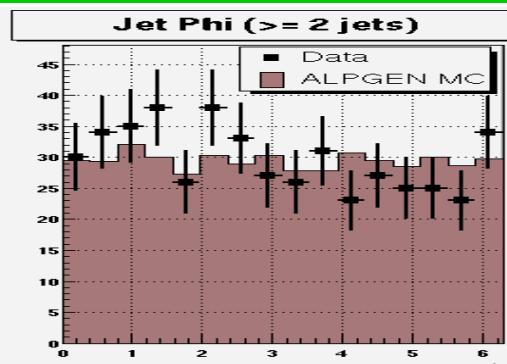
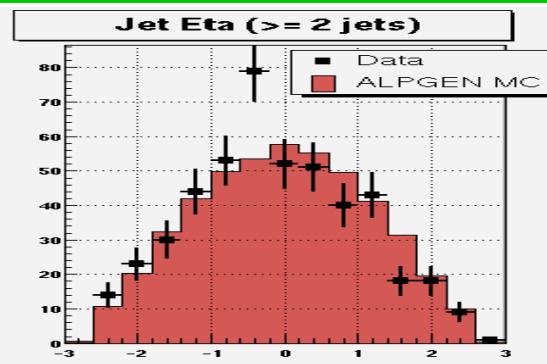
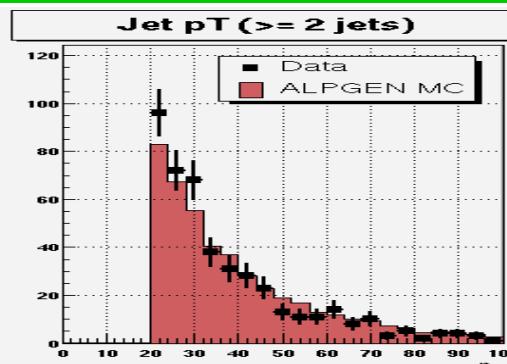
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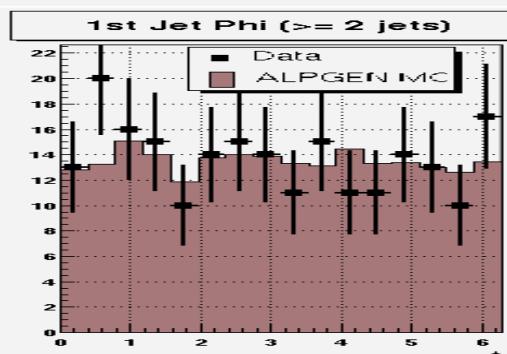
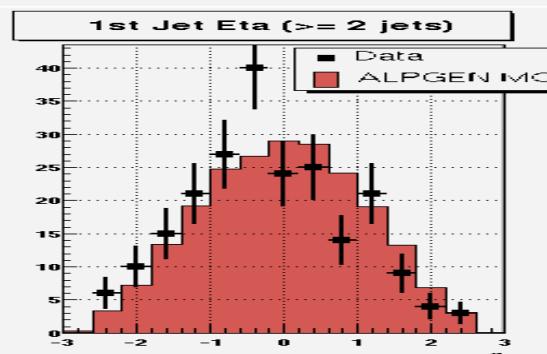
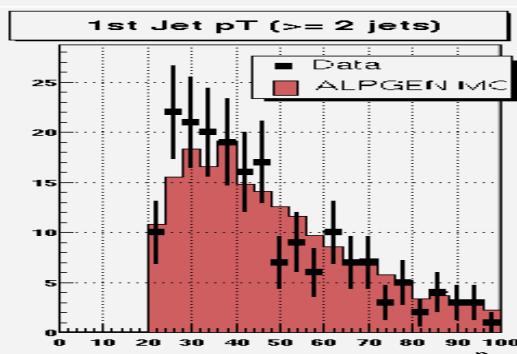
17

# $Z(ee) + \geq 2$ jet(s): Jets

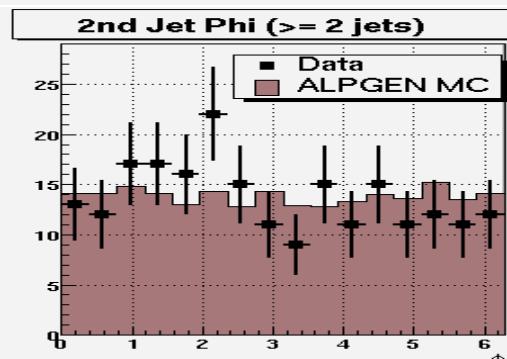
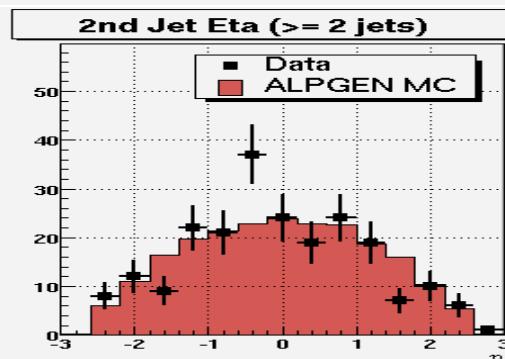
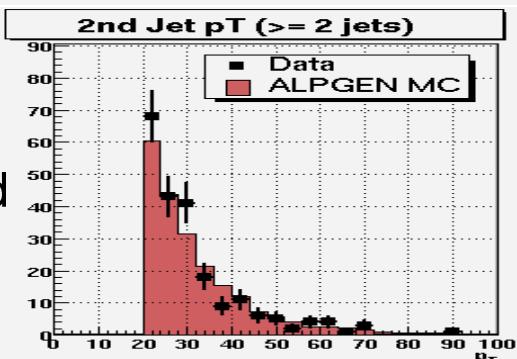
All



1st



2nd



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18

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# Unsmearing

# Concept

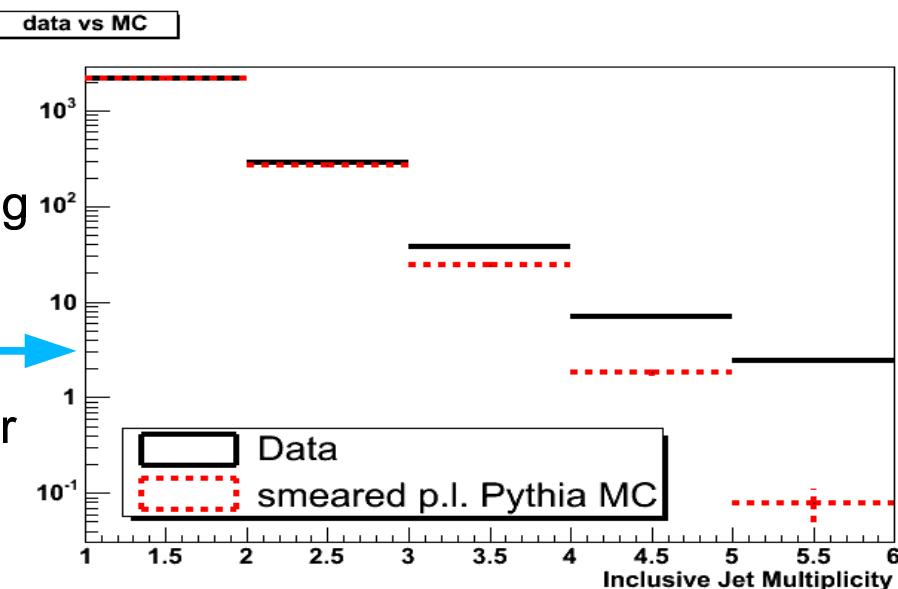
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- In order to determine particle level cross sections, we unsmear the measured data jet multiplicities
- We use a Z+j Pythia sample (2-to-2 processes) which only contains particle level jets (no detector simulation)
- To be able to compare to data we smear the jet pT and also apply the jet reco/ID efficiencies
- In MC we ...
  - ... get the inclusive jet multiplicity histogram for particle level jets with  $pT > 20\text{GeV}$  and  $|\eta_{\text{phys}}| < 2.5$
  - ... get the inclusive jet multiplicity histogram for particle level jets with **smeared**  $pT > 20\text{GeV}$  and  $|\eta_{\text{phys}}| < 2.5$  (plus application of jet reco/ID efficiencies)
  - ... take the ratio between the two histograms to get the unsmearing coefficients
  - ... apply the unsmeering & jet reco/ID coefficients to the measured data jet multiplicities in data to unsmear

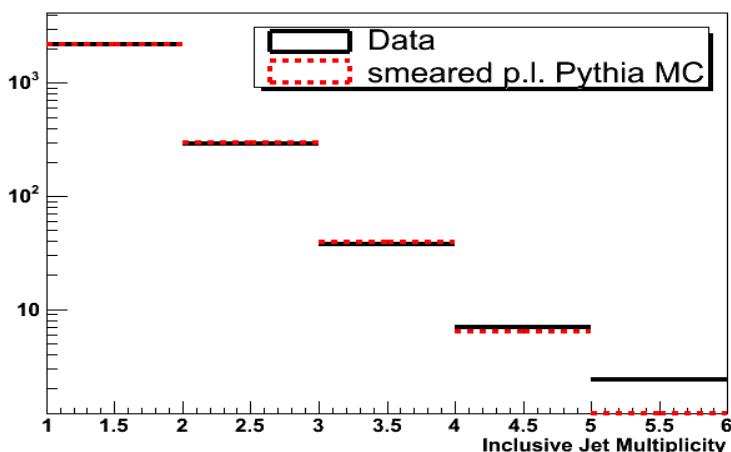
# 'Fixing' Pythia

Comparing the inclusive jet multiplicities for the smeared p.l. MC with data, shows increasing disagreement at higher jet multiplicities.

Pythia doesn't include higher order contributions at the hard scatter level.

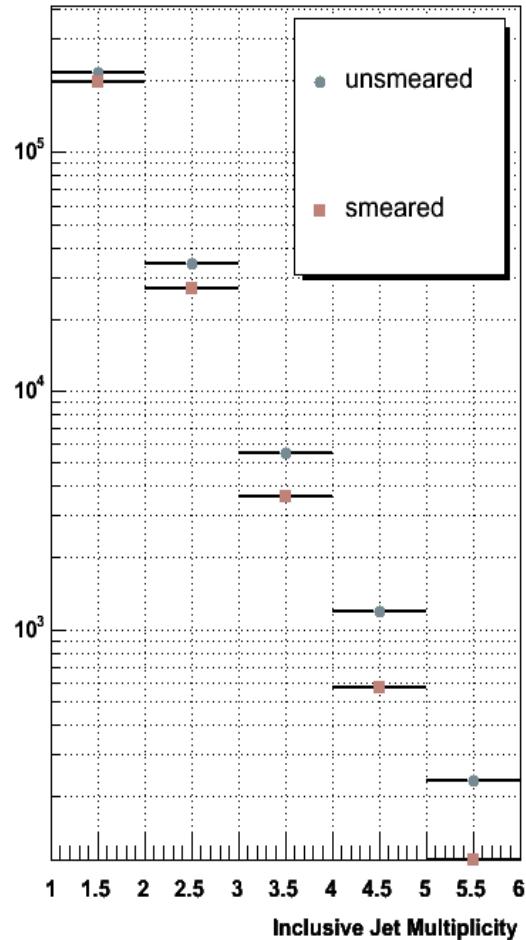


We apply the ratio between data and MC as a correction to 'fix' Pythia.

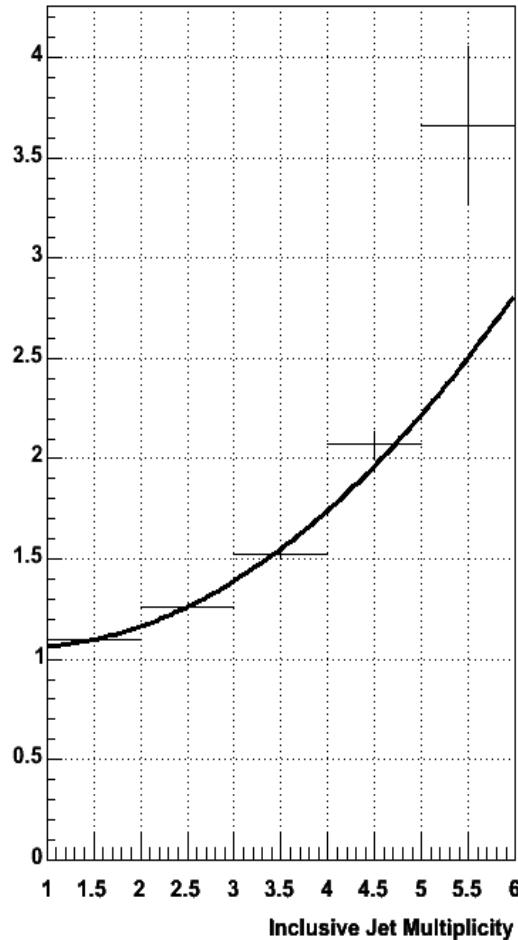


# Unsmearing Coefficients

num\_jets\_incl\_h



Unsmearing coefficients



Jet Mult	Unsm. Coeff.*
1	1.10+-0.07
2	1.26+-0.16
3	1.55+-0.28
4	1.97+-0.44
5	2.51+-1.89

(\* includes jet reco/ ID,  
errors are syst. Uncert.  
Due to resolution, jet  
reco/ ID and bin 5)

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# **Electron-Jet-Overlap Correction**

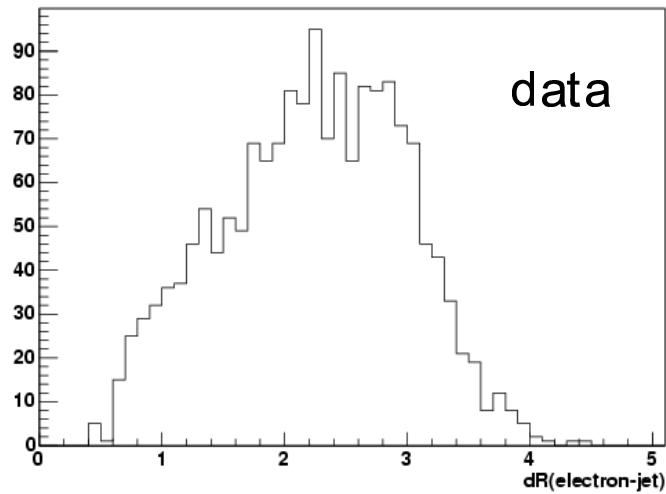
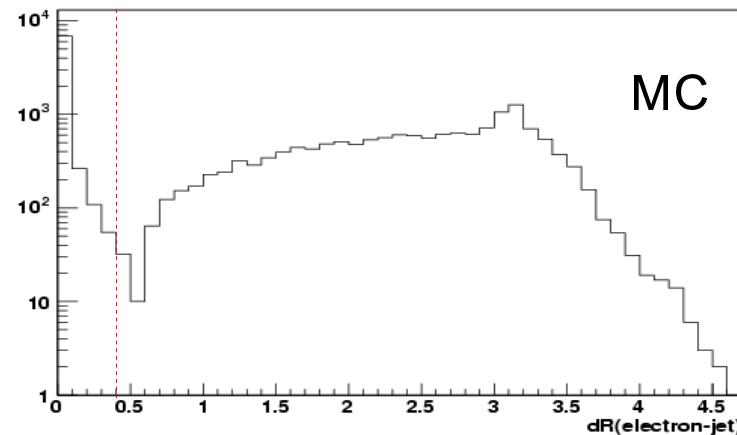
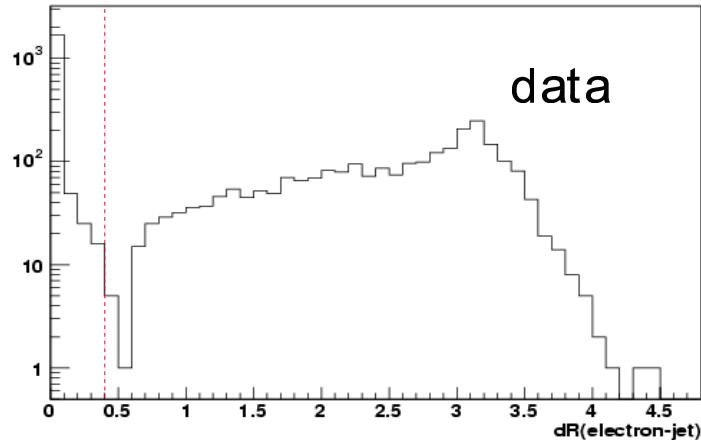


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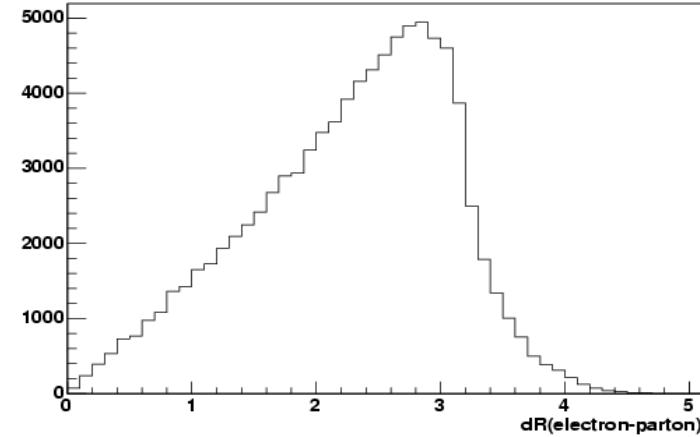
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# $dR(\text{Electrons} - \text{Jets})$

$dR$  between probe-tracks and good jets w/o elec-jet-overlap cut:



with elec-jet-overlap cut



$dR$  between generated elecs and partons



# Correction Factors

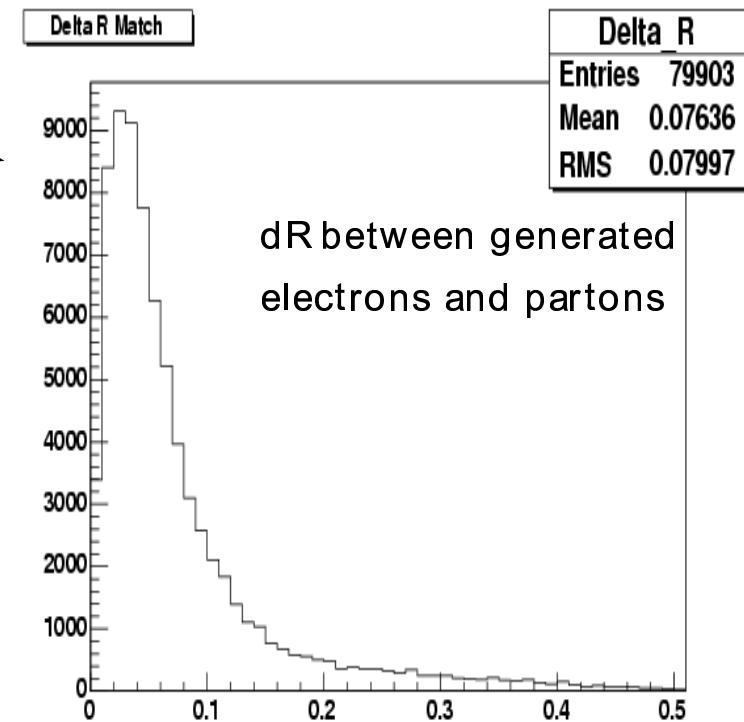
- We correct for real jets that are removed by elec-jet-overlap cut:

Incl. parton multipl. for all partons

Incl. Parton multipl. for partons outside of dR cone

- We derive corrections using dR=0.4 and dR=0.7 and take the middle value (position resolution)

Jet Mult	Coefficient
1	1.059+-0.028
2	1.075+-0.041
3	1.092+-0.054
4	1.109+-0.067
5	1.125+-0.077

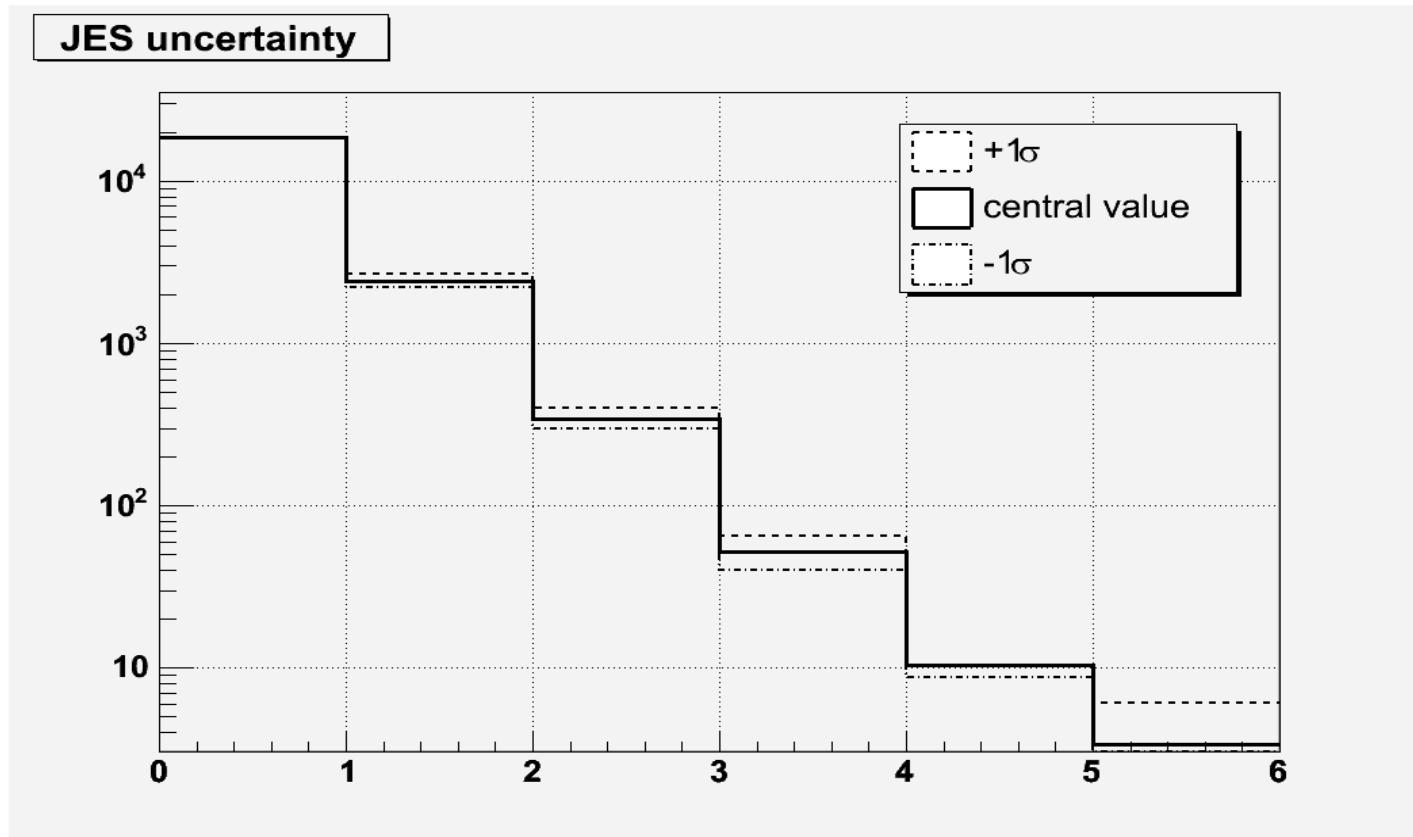


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# Systematics

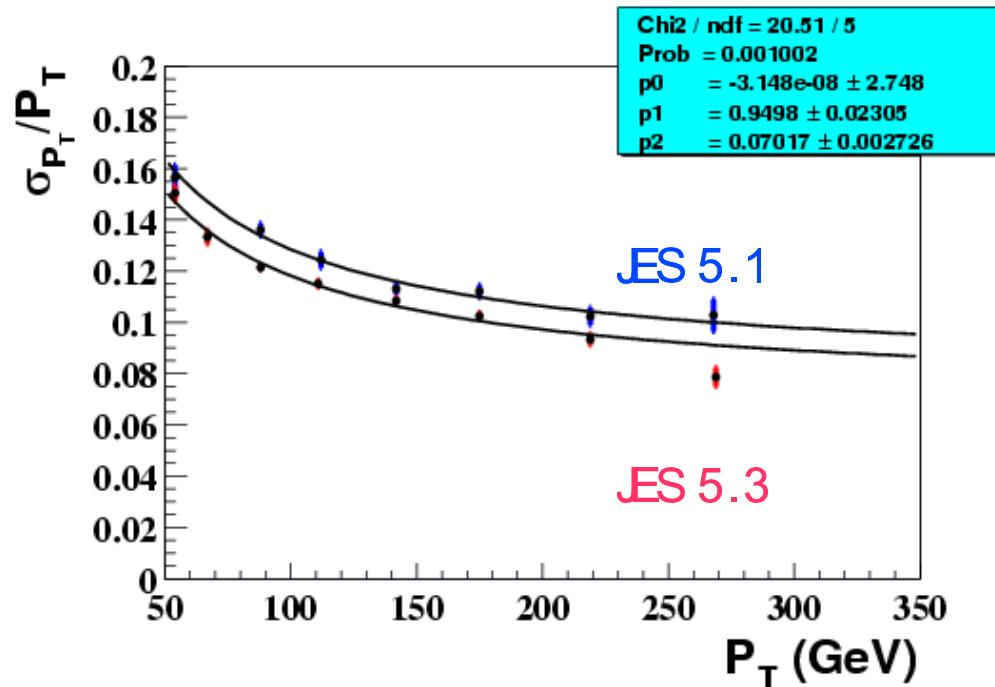
# JES Systematic Error

- We vary the JES (5.3) by +1sigma:  
corrected jet pT = uncorrected jet pT x (JES correction +- JES error)



# Syst. Error of Cross Section Unfolding

- Jet reco/ID errors: statistics, MET (see previous slides)
- Jet resolution: need to account for the difference between JES 5.0 and JES 5.3



Difference is 5% over  
the whole range.  
We assign 10%

- Bin 5 error: 46% uncertainty due to fit of unsmeearing coefficient

# Other systematics

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- Electron-Jet-Overlap: Error = difference between the middle value and the  $dR=0.4(0.7)$  values
- Efficiencies: systematics are estimated using the **event based** efficiencies for trigger, EMreco/ID, and EM-Track efficiencies (systematics quoted in chapters 5.1.1-5.1.3)

# Jet Promotion study

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- Jet Promotion = gaining additional jets from multiple interactions within the same beam crossing
- We compare jet multiplicities for events that have exactly one reco'd P.V. with events that have at least two reco'd P.V.'s

Jet Multiplicity	1 P.V.	$\geq 2$ P.V.
0	5,900	5,900
1	705	696
2	92	97
3	11	16
4	3	1
5	1	1

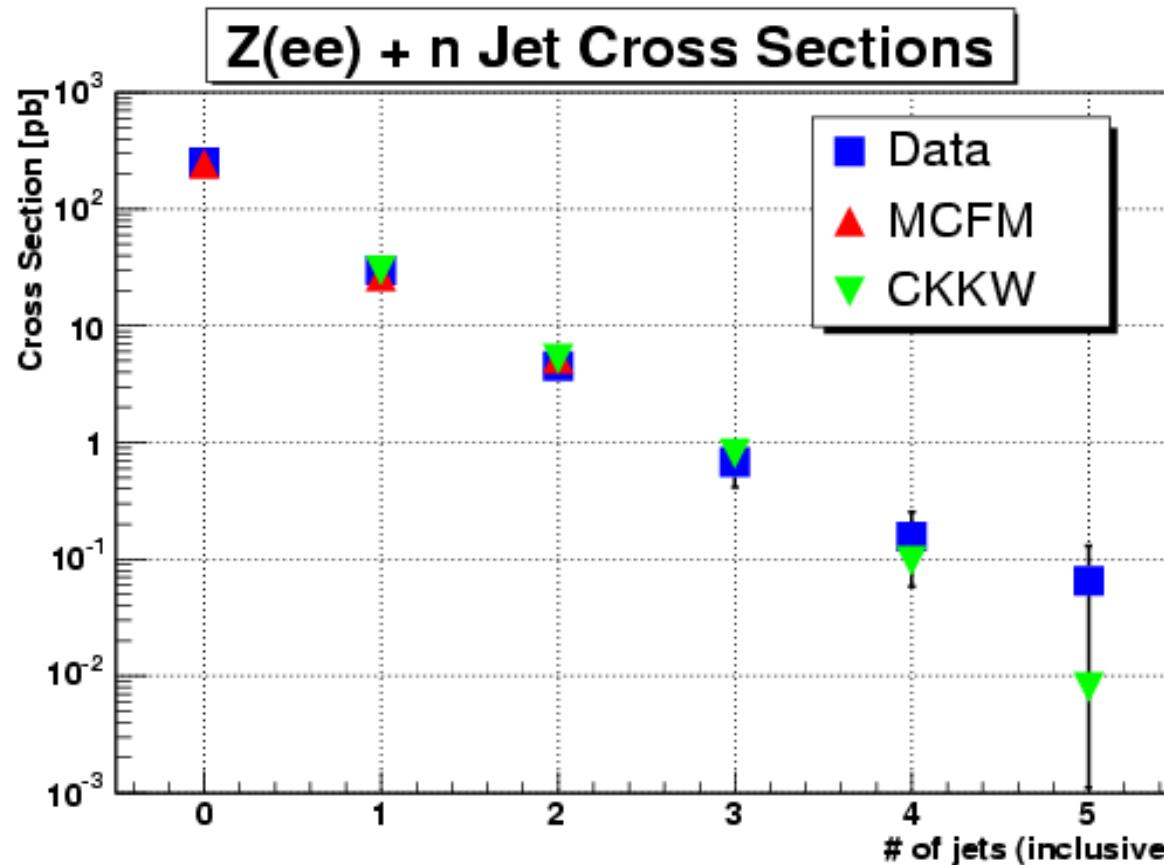
- Jet promotion effect is small since the discrepancy between the two samples is within statistical errors
- We are planning on studying this effect in more detail using a large MB sample

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# $Z(ee) + \geq n$ Jet cross sections

# Cross Sections

Xsection = (# of corrected & unsmeared signal events) / (Lumi x Acceptance)



# Plans

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- Normalization of xsections wrt  $Z(ee) + X$   
xsection (ratios)
- Study additional physics backgrounds in MC
- Include vertex efficiency

